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ALKALI SOILS

ORIGIN, EXAMINATION, AND MANAGEMENT

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Considerable areas of productive soils are still in the process of being injured or ruined by alkali, with consequent great economic loss. Very much of this loss could be avoided by proper handling of the soil and irrigation water by known methods. In some cases, soils which are now of little use on account of alkali may be made to produce much more abundantly by good management, including some not very expensive treatment.

The purpose of this circular is to present in brief form the best available information on the subject of alkali soils in respect to origin, nature, effects, examination, treatment, and cropping. The reader may observe a lack of the specific or definite statements which he would prefer to the somewhat general statements that are made in several places in this circular. The reason is that definite and reliable information in regard to many points is not yet available, so that only somewhat generalized statements are now possible. The purpose is to restate the older views as modified by recent investigations carried on in California and elsewhere.

That prevention is cheaper than cure is most emphatically true of alkali soils. To prevent further injury to good soils by alkali should be considered by every public official who has any authority in such matters, as one of his most important duties. Likewise, every farmer should try to manage his land in such manner as to prevent further spread of alkali.

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1. *What is Alkali?*

As commonly used the word ''alkali'' has no precise meaning. In order to promote clearness in the present discussion ''alkali'' is defined as follows: White alkali consists of one or more of the non-alkaline salts of sodium, such as the chloride, the sulfate, or the nitrate. Black alkali consists of the truly alkaline salts of sodium, namely, the bicarbonate, known as baking soda, and the carbonate, known as sal soda. Occasionally one or more of the corresponding compounds of calcium or magnesium may be spoken of as alkali.

2. *What is the Origin or Source of Alkali?*

All forms of alkali are derived primarily from the original rocks. Most soils consist largely of pulverized and somewhat decomposed rock and therefore are potential sources of alkali. When the rocks are decomposed by weathering, the various forms of alkali are set free. All forms of alkali are easily soluble in water. Consequently if the rainfall is sufficient, the alkali coming from decomposition of rock material is carried away into the rivers, thence to the ocean, or into some inland lake.

During past times, parts of the ocean were separated from the main body of water by changes in elevation of portions of the land, and have dried up. In this way, salt beds and alkali deposits were formed. These may now lie far below the surface of the ground. When water is drawn from such places, it is found to contain alkali. If this water is used for irrigation, the salts are deposited on the ground, thus producing an alkali soil.

In arid countries, there is not enough rain to wash away the salts which are slowly being formed in the body of the soil itself by decomposition of the rock fragments. When such land is irrigated copiously, without adequate drainage, the water table is very likely to rise toward the surface and bring up with it most of the salts from the whole body of soil. In this way, the salts which were formerly distributed through fifty feet of soil may be concentrated in the few feet at the top where evaporation from the surface will cause them to appear as an alkali crust. Briefly, then, alkali originates through decay of the original rocks and is then brought to the surface of the land by the agency of water. *Evidently if good irrigating water is properly and not excessively used, there will be no alkali problem on land not already containing alkali—provided, of course, that the drainage is good.*

3. *What is the Difference Between White and Black Alkali?*

White alkali consists of the neutral salts, chiefly sodium chloride and sulfate, which are not caustic or corrosive and do not deflocculate the soil.* Black alkali consists of the bicarbonate and the carbonate of sodium which are truly alkaline and often corrosive to plants. These salts deflocculate the soil and injure it severely. White alkali is comparatively easily washed out of the soil by water, but black alkali, owing to the deflocculation it causes, is very difficult to remove by water alone.

4. *Is it Possible to Make Black Alkali from White Alkali?*

To some extent, this conversion may be brought about in two ways: (*a*) When water containing white alkali is percolated through soil containing much calcium carbonate, some sodium carbonate (black alkali) may be formed. (*b*) If the soil contains no calcium carbonate, water containing white alkali percolating through it may so change the composition of certain of the mineral constituents that when the soil is leached with *pure* water, some sodium carbonate may be produced. When this occurs it is manifested by deflocculation and other bad effects known to be caused by black alkali. In either case, the production of sodium carbonate may be largely or entirely prevented by the use of sufficient gypsum. This may be applied by dissolving it in the irrigating water, or by spreading it on the land before irrigating. Since it is possible to produce black alkali in the soil by leaching out white alkali, it is very important to avoid adding white alkali to the soil with irrigating water or in any other way.

5. *What are the Effects of Alkali on Plants?*

Most agricultural plants are injured by large amounts of any easily soluble salt in the soil. Much of the harm is caused by the effect of the salt in deranging the normal water relations existing between the plant and the soil. Because of the high concentration of salts in the soil moisture, the plant cannot obtain its normal supply of water. Also, it is possible that the presence of sodium salts may interfere with

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* The finer portions of most normal soils are united into groups or bundles or crumbs, often spoken of as floccules. When the soil is properly managed these floccules remain intact. Ordinary cultivation or handling does not break them up. If the soil is shaken with water, worked when very wet, or treated with certain chemicals, such as black alkali, the compound bundles or floccules are broken up into much smaller particles. That is, the soil is deflocculated, or, as a farmer mght say, the soil is puddled. Deflocculation of a soil is very injurious to its agricultural value, and greatly increases the difficulties of tillage. Deflocculation greatly decreases the rate of percolation of water through a soil, makes it more sticky when wet, and tends to produce very hard clods when the soil dries.

the normal absorption or utilization of the necessary nutrients. Thus, alkali salts sometimes produce difficulties of nutrition in plants, even when the concentration is not sufficient to disturb seriously the water relations referred to.

Black alkali acts much like white alkali in general, but also produces certain effects peculiar to itself. Small amounts may change the composition of the soil moisture so that plants cannot obtain enough iron, lime, or phosphorus, to maintain healthy growth. Large amounts of black alkali, in addition to the harmful effects already mentioned, have a corrosive and decomposing action on the bark of the roots, which may destroy the plant. Different kinds of plants differ greatly in their ability to endure the evil effects of alkali. The so-called alkali plants of the desert live in the presence of quantities of alkali which prevent the growth of most cultivated plants.

Alkali injury is manifested by poor, stunted, or abnormal growth, drying or curling up of leaves, or sometimes yellowing, mottling, or other discoloration, or loss of leaves. New growth may appear, but soon dies away. Some of these effects may be caused by lack of water, even in the absence of alkali, so it is not always possible to tell by the appearance whether injury to a plant is caused by alkali or by lack of water, or by both.

The bad effects of alkali are diminished by plenty of water, so that a change of season may greatly modify the effect of a given amount of alkali on the plant. During cool weather, the plant does not need so much water, since evaporation from leaf surfaces and from the soil is much slower when the air is cool and moist. Therefore, an amount of alkali in the soil which would be very injurious in summer, may have only a mildly retarding effect on the plant in the winter.

6. *What is the Effect of Alkali on the Soil?*

Moderate amounts of white alkali have very little apparent effect on the soil. Large amounts cause the soil to swell somewhat and to become light and fluffy. When white alkali is washed out of the soil, there is (as already mentioned under Section 4), very likely to be produced a small amount of black alkali with its usual bad effects, to be described below. When the soil contains a large amount of salts, particularly calcium chloride or nitrate, it may remain permanently moist, even in the driest part of the summer. Such soils are sometimes mistaken for black alkali soils. It is probable that hardpan is often generated by the action of alkali in combination with effects produced by the movement of water up and down in the soil. The finer the texture of the soil—the more clay it contains—the greater are the changes produced in it by alkali.

Small amounts of black alkali have very marked effects on the soil, causing deflocculation or loss of crumb structure so that the particles of soil approach each other more closely, thus producing shrinkage which may cause low spots in the field. The soil becomes much more sticky when wet and much less easily penetrated by water when dry. After a heavy rain, the low alkali spots remain covered with water after the non-alkali ground is dry. When black alkali soils dry, they bake and form hard clods. Such an alkali soil is likely to be much more difficult to till than the same soil when free of alkali. Black alkali prevents iron and calcium (and phosphorus under some circumstances) from dissolving in the soil moisture so that these elements may become more or less unavailable to plants, and growth be much hindered.

7. *How May the Injurious Effects of Alkali on Soil be Prevented?*

Use only good water for irrigating. Good water should contain very little of any of the alkali salts. If good water cannot be had, it may be better to use such water as is available, rather than none, but with the distinct understanding that alkali water is liable to ruin the soil eventually. Avoid using an excess of water. Prevent leakage and seepage from canals and ditches. Have a good distributing system so that the water is evenly applied and allowed to penetrate uniformly all over the field. In case the irrigating water contains salts, accumulation of alkali may be largely prevented by flooding the land once a year so that the accumulated salts are carried away in the drainage, down into the ground so deep that none will return to the surface again.

In all cases where much irrigation water is used, it is important to have some adequate means of drainage which will prevent the rise of the water table too near to the surface. The distance at which it becomes dangerous varies with the character of the soil. If it comes close to the top, salts are likely to be brought to the surface by capillary action and thus produce an alkali crust or a dangerous concentration of salts in the region of plant roots. This danger was pointed out by Hilgard in Bulletin 53 of this Station, published in 1886.

The production of harmful concentrations of alkali is much delayed by any means which reduces evaporation at the surface, such as growing crops which shade the soil, growing deep-rooting crops which draw their moisture from far below the surface, or by any other means which keeps the alkali distributed through a large body of soil, instead of allowing it to concentrate near the surface. The bad effects of a small amount of black alkali may be diminished, or sometimes entirely avoided by the use of gypsum, sulfur, or other chemicals. Manure and green cover crops will help to relieve the evil if the soil is sup-

plied with lime. Decaying vegetable matter helps to make lime soluble in the soil moisture so that plants can absorb it, and it can act beneficially on the soil.

When it is desired to start sensitive crops on alkali soil, the surface crust may be plowed under, thus giving the young plants time to get a start before the alkali again comes to the top. A better procedure is to leach the salts down deeply into the soil by heavy irrigation before seeding. When trees are planted, they are helped by filling in around them with good soil, instead of the alkali soil that was thrown out in digging the hole. Any kind of fertilizer or manure that enables plants to obtain their nutriment more easily will assist in reducing the bad effects of alkali.

8. *How Can Alkali be Removed from the Soil?*

First cut off incoming alkali, by proper management of water supply and drainage. Second, discover, if possible, the kind, amount and location of the alkali as a basis for estimating the cost of reclamation. White alkali may be removed by flooding with good water. The presence of gypsum or lime in the leaching water is desirable or essential in order to avoid formation of black alkali following removal of the sodium salts. More than one treatment may be necessary. Leaching out in this way requires good drainage. Drainage may be improved by ditches, tiling, dynamiting to break up hardpan, and by sump wells into which the water may flow. The drainage question frequently may be a very difficult one to solve. The advice of a drainage engineer should be sought.

Small amounts of black alkali may be neutralized by addition to the soil of gypsum, sulfur, acids, alum or of some other chemicals, without trying to leach out the salts. Large amounts of black alkali are exceedingly difficult to remove. Years of patient and perhaps expensive treatment may be required. The economic feasibility of reclaiming some black alkali soils has yet to be demonstrated.

The chemicals just mentioned change black alkali into white alkali. If large amounts of the latter are present, they must then be leached out before the soil will become suitable for crops. In consequence of the severe leaching required to remove large amounts of salts, most of the soluble plant food also is washed away with the alkali, so that a leached alkali soil is likely to be very infertile. This may make it necessary to use some kind of fertilizer to get a crop started. After that, the fertility of the land may be gradually restored by the use of green manure crops. *The California Experiment Station is still investigating alkali problems, and in many cases conclusive recommendations must await the outcome of further experimentation.*

9. *Importance of Preventing Spread of Alkali.*

No argument is necessary to show that it is better to prevent the intrusion of alkali than to try to remove it after it has gotten into the soil. Prevention is very much less expensive than cure. Great economic loss results from the decreased productivity of alkalied land. As just stated, reclamation methods are not yet well worked out and, besides, are very expensive in both time and money. Public officials, as well as private agencies, should do all in their power to prevent the spread of alkali into good land.

10. *How Much Alkali May the Soil Contain Without Causing Injury to Crops?*

This question cannot be answered definitely or precisely for the reason that conditions other than the amount of alkali greatly modify the effect of the alkali itself. Since all of these factors vary greatly from time to time and are little subject to control by man, manifestly it is possible to make only the most general statement as to how much alkali will cause trouble.

Hilgard has stated that the limits of tolerance for alkali salts are somewhat as follows:

Sodium carbonate	0.1% to 0.25%
Sodium chloride	0.2% to 0.50%, and
Sodium sulfate	0.5% to 1.00% of the soil.

Our experience is that much smaller amounts may be very injurious in some cases, and larger amounts may cause little troube in other cases.

The limited scope of the present treatment permits only brief mention of the principal variable factors which influence the effect of alkali.

(*a*) The kind of alkali. The relative toxicity of the several salts has often been found to be approximately that indicated above.

(*b*) The location of the alkali in the soil, whether mostly near the top, or uniformly distributed through the zone of plant roots, or little at the top and in greater concentration lower down, will greatly modify its effects on the plant, according to its habits of growth and the character of its rooting system, whether deep or shallow, etc.

(*c*) The physical character of the soil, whether sand, silt, loam, clay, or peat, materially changes the effect of a given amount of alkali. The more sand there is in a soil the more injurious to plants is the effect of a given amount of alkali, and the less the apparent change in the physical condition of the soil. On the other hand the greater the

amount of clay in a soil, the less harmful to plants is a given amount of alkali, but the greater is the injury to the physical character of the soil. When clay contains much black alkali, ordinary tillage may be very difficult, perhaps impossible. A large amount of organic matter such as is contained in a peat soil, greatly reduces the harmful effects of salts on plants growing in the soil.

(*d*) The natural fertility of the soil itself apart from alkali may make much difference. The more fertile the soil, the better will plants endure the harmful effects of alkali. A liberal use of fertilizers may permit production of a good crop on soil containing so much salts that without the fertilizer, little could be grown. These are only general observations. It should not be assumed that the addition of fertilizers will prevent alkali injury.

(*e*) The amount and timeliness of the moisture supply in the soil is very important in respect to alkali. The more moisture in the soil, the lower will be the concentration of alkali in the soil moisture and the less harm will the alkali do. This implies that the supply of moisture must be kept up, for if the ground should become very dry, the concentration of alkali in the soil moisture might become great enough to injure the plants.

(*f*) Climate and season of the year in relation to the growth period of the crop will influence the results materially. It has been found that an amount of salt which was very injurious to wheat in the summer time, did little harm in the cooler weather of winter. This is partly because alkali is brought to the surface by capillarity (with evaporation of water), while in winter it is washed down by rains into lower depths, and also because crops suffer greater injury from alkali in hot, dry weather than in cool moist weather, as already stated in Section (*e*).

(*g*) Most important of all is the tolerance of the plant itself. This subject is considered in the next section.

11. *What is the Tolerance of Various Crops for Alkali?*

As stated in more detail in the preceding section, the capacity of any plant to endure alkali varies greatly with the physical character of the soil, whether sand, loam, clay, or peat, with the kind, amount and location of the alkali, with the fertility of the soil, with the water supply, the climate and other factors. Consequetly, it is not possible to indicate the tolerance of any plant, except in a very general way. Even in any one species of plants, some varieties are much more tolerant than others.

In considering what is likely to be the most successful crop on alkali soil, or whether any particular crop will do well, attention to the following points is important:

How will the alkali affect germination of the seed? Germination may be delayed or prevented by alkali.

Will the young seedlings be injured? Most young plants are very sensitive and easily injured.

Can proper moisture conditions be maintained during germination and the seedling stage? If the soil becomes dry, the alkali is more likely to injure plants.

Is the mature plant resistant to alkali? Some plants, for example, alfalfa, are very sensitive in the seedling stage, but can endure a good deal when fairly mature.

Is the root system of the plant adapted to the particular conditions of the soil, moisture and alkali in this place? [See (*b*) under Section 10, p. 7.]

How will the plant be affected by flooding or other conditions which may be incidental to reclamation procedures? Some plants can endure standing water for many hours, others are quickly injured if the soil is covered with water.

Can tillage be managed so that there will be little tendency to cause rise of alkali to the top of the soil where it is most harmful? This last is to be considered in connection with the fact that for most plants the alkali is likely to be less injurious if it can be kept distributed through the whole body of the soil, than if allowed to concentrate near the surface.

In general, the grasses, which include all our cultivated grains, are more resistant to alkali than most crops, though bluegrass and some other grasses are very sensitive to alkali. Wheat, barley, and milo endure alkali better than corn. Bermuda grass and Rhodes grass are exceptionally tolerant of black alkali.

The legumes are generally rather sensitive to alkali, with some marked exceptions. Alfalfa, *when old*, will endure a good deal, so will melilotus (sweet clover) and hairy vetch. Beans and peas are easily injured. Root crops like beets and onions are quite tolerant of alkali. Melons are very sensitive. Most fruit trees are easily injured. General observations in the field indicate that walnut and citrus trees are most sensitive, next come apples, apricots, plums, prunes, peaches, pears and grapes, while olives are most tolerant of alkali. This order of relative resistance to alkali will vary in different soils and with different kinds or combinations of alkali.

12. *Is Alkali Uniformly Distributed in the Soil?*

Any one who has had experience with alkali knows that it is exceedingly variable. "Alkali spots" in fields are commonly known as areas where so much alkali is present that there is very poor or no growth of plants. A little thought should convince one that since there is evident variation in amount of alkali between the good soil and the alkali spots, that there is likely to be variation between other places although they may appear similar to the eye. But if one may judge from the inquiries that are frequently received at the experiment station, many persons do not realize the enormous difference in the amount of alkali present in spots often very close together. Actually the amount may be 5 or 10 times as much in one place as in another, only one or two feet distant. It is on account of this great variability that it is so difficult to find out how much alkali there is in any certain field, and also the tolerance of crops for alkali. Some of the causes of this variability in distribution of alkali are: physical inequalities in the soil, and changes caused by movement of water, growth of crops, and tillage. The salts in the soil are constantly being moved about, up or down, or horizontally, by the changes in amount and location of the soil moisture, induced by rain, irrigation, rise or fall of the water table, if near the surface, and withdrawal of moisture by growing crops. In these movements caused by changes in position of the soil moisture, some of the salts are moved through the soil faster than others. Thus some of the inequalities in distribution of alkali are produced. On account of these great variations in alkali content, a single sample or even several samples of soil from any field cannot be expected to give a correct idea of the actual amount of salts in the soil of the whole field, or indicate precisely how any particular crop on the land would be affected by the salts present. Only by taking a great number of samples, each to be tested separately, or possibly after being composited, can the alkali content of any field be determined with even approximate accuracy. This is too expensive for any ordinary practical purpose.

13. *What Value has a Chemical Analysis of Alkali Soils?*

Considering that there is such great variation in alkali soil, it may appear futile to make a chemical analysis of the soil for the purpose of determining the amount of alkali in any one spot. This would be true if it were necessary to know with approximate accuracy the amount and kind of salts present in the whole field. But this is not necessary in order to decide upon a general treatment of the soil for removal of the alkali, or to select a suitable crop to be grown. If the analysis

shows no alkali in the sample examined, this should be regarded as only a general indication. Alkali might be present to an injurious extent in other portions of the field. But if some alkali is found in the sample examined, it is quite possible that there is enough present in many places in the field to make trouble. The presence of alkali in any sample is a cause for suspicion so that it may become advisable to test other samples from many places in order to obtain a better representation of the whole area. This is expensive, but necessary if reasonable certainty is desired. Instead of taking so many samples, it may be taken for granted, on the basis of the results obtained from a few samples that either (*a*) there is no alkali in the soil, or, (*b*) if alkali is found, suitable treatment may be recommended. This is the usual custom. In any case, the treatment is applied uniformly so that some spots receive unnecessary attention and others are inadequately treated. After some time, other tests may be made on samples taken from as nearly as possible the same spots, to learn whether the desired effects are being produced. The growth of crops will also serve to indicate which spots require further treatment.

Chemical tests are valuable to show whether alkali is present, and if so, what kind, and to suggest means of removing it, even though the sample examined does not truly represent the whole area. If no alkali is found, it is in order to seek some other cause for the failure of crops on the land.

14. *What is the Proper Way to Take Soil Samples to be Tested for Alkali?*

Before taking samples of soil, or sending them to be tested, the inquirer should try to decide whether any test or analysis is needed, whether a test can answer the question he has in mind, or indicate how the soil should be treated. *In making this decision the farm advisor should be consulted.*

If there is a good growth of vegetation, or any kind of successful crop on the land, it would be a waste of time to make tests for alkali, for there is evidently not enough to do much harm. If it is already known from observation or experience that the soil contains alkali, no test is needed to show its presence, although a test may be desirable to indicate the best method for reclamation. There is no use in having an analysis of soil made for the purpose of determining crop adaptation or fertilizer requirements. It is not yet possible to predict from the results of a soil analysis what crops will do well on the land, or what fertilizer, if any, will produce the most benefit. Such practical questions can best be answered by a knowledge of the general condi-

tions of the locality. Find out what is growing well on similar soil nearby. If a certain crop is a failure on one piece of land, it may fail on other similar neighboring land similarly managed. Whether any fertilizer is needed or will pay must be found out by actual trials in the field and by careful consideration of the cost of production in relation to market prices. The advice of one who knows the country, namely the farm advisor, is most useful in answering all these questions.

The following instructions are intended particularly for those cases where it is desired to determine the presence or absence of alkali by taking one or a few samples, but not for the purpose of an alkali survey.

15. *Instructions for Taking Samples to be Tested.*

Select a spot where alkali is most likely to be found. If there is any surface crust apparent, take a sample and mark it ''surface.'' Bore down with a soil auger one foot. Collect the borings on a piece of canvas or oil cloth and mix well. Of this mixture, take a portion of ½ to 1 pound and mark the sample ''Hole 1, first foot.'' Now bore down to the bottom of the second foot, mix the boring, take a sample as before and mark it ''Hole 1, second foot.'' Continue with the third and fourth feet in similar manner. An excellent method of marking the samples is as follows: Instead of writing ''Hole 1, first foot, second foot,'' etc., write simply 1.1, 1.2, 1.3, 1.4, on the samples from the first hole, then 2.1, 2.2, 2.3, and 2.4, on samples from the second hole, etc. The samples are most conveniently kept in stout paper bags which are easily marked. If the soil is moist, it should be dried before the samples are packed for shipping, in order to avoid breakage of packages and loss of samples.

Samples thus properly taken from a few holes in well selected places, should give a very good idea of the land in respect to alkali. But if only a few lumps of soil from the surface are taken, it is hardly worth while to test them. Such grab samples cannot be considered to represent anything but themselves. To base a decision as to the condition of a piece of land on the results of an examination of one or two surface samples, is scarcely better than guessing at it. The condition of the soil to at least four feet in depth should be determined in more than one place. An alkali survey to ascertain quite accurately the amount and kind of alkali in a piece of land requires systematic sampling in many places. This is quite expensive and probably not necessary for most practical purposes.

Any one who desires assistance or advice in regard to soil problems should first consult the county farm advisor. He may be able to settle the question without going further. But if he cannot give the desired information, he will direct the inquirer how to proceed to obtain any available information on the subject. The name and address of the farm advisor for any particular county may be obtained upon request from the Division of Agricultural Extension, University of California, Berkeley, California.

If samples of soil are sent to be tested, a letter should be sent *at the same time,* but separately from the samples, with full information on the following points:

Sent by .... Address ....

From Ranch of .... Date sent..........................

Mark on samples ....

Location of land .... Sec. ....Township ....Range ....

Topography of land: Level, rolling, hilly, swampy ....

Physical character of soils: Sand, fine sand, silt, silt loam, clay loam, adobe, clay, muck, peat, hardpan at .... feet depth, calcareous ....

Area: How many acres, approximately ....

Drainage: Is the ground level, or sloping, underlaid by gravel, sand or clay? ....

Water table: How far below surface? ....

Irrigation water: From .... river, lake, spring, well. Is it abundant or scarce? .... What is its quality, good, saline, alkaline? ....

Crops now, or recently growing: ....

Crop desired to produce: ....

Character of suspected trouble: Alkali, salts, acidity ....

Is the sample average, or better, or worse than the average of the field?............ ....

Remarks (Add here other pertinent information): ....
....
....
....

Importance of Proper Packing.—Packages containing soil enclosed in thin paper, thin paper bags or other flimsy materials are liable to be broken in transit so that the samples are mixed or lost. *Metal or wooden boxes, stout cloth sacks, or strong paper bags if packed in boxes or heavy paper,* are suitable containers for soil samples. The soil should be dry before it is packed.

Importance of Labelling.—Good labelling is as important as adequate sampling, therefore, be sure that the writing on the labels is distinct and permanent. Indistinct, or otherwise inadequate, marking often causes difficulty in giving a satisfactory report. Mark each sample plainly. The address of the sender should be placed on the outside of the package.

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